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HENRY O'MALLEY, Commissioner

EXPERIMENTS IN THE ARTIFICIAL PROPAGATION OF OYSTERS

BY

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APPENDIX XI TO THE REPORT OF THE U. S. COMMISSIONER OF FISHERIES FOR 1923

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INTRODUCTION.

The great oyster fisheries of the Atlantic coast have in the past few years experienced an alarming decline in productiveness. Though the extensive methods of oyster culture practiced by many of the oyster growers have assisted greatly in maintaining a constant supply, they have not been sufficiently reliable to guarantee a crop from year to year. The rapid decline of this valuable industry has been brought about by a constant depletion of the oyster beds from various factors, such as pollution, overfishing, unfavorable climatic and hydrographic conditions, natural enemies, and use of shells for various commercial purposes.

Careful scientific studies of the life history and environment of the oyster have assisted greatly in improving the cultural methods now in use but have not perfected them to such an extent that an annual harvest can be relied upon from year to year. Briefly stated,

[1] Appendix XI to the Report of the U. S. Commissioner of Fisheries for 1923. B. F. Doc. 961.

oyster culture in the United States consists of (1) acquiring suitable submerged bottom, (2) cleaning and preparing that bottom for the growth of oysters, (3) sowing thereon shells or other material (cultch) for the attachment and growth of the young oysters, (4) insuring the production of larval oysters by the proximity of natural or planted beds of adult oysters, (5) protecting the oyster beds from enemies, (6) transplanting as occasion requires to prevent overcrowding and to facilitate growth and fattening, and (7) culling and sorting for market.[2]

To conduct oyster cultivation along such lines a considerable investment of capital is necessary, and the yearly program involves a heavy expense in preparing to catch a "set" of the young oysters. In the event of a failure to obtain a good "set," which unfortunately has been the common occurrence of late years, the expenditure that has been made is a total loss, and is further increased if the cultch is taken up and dried out for use the following year.

Consequently the aim of oyster growers and biologists interested in this work is to place oyster culture on such a basis that a harvest may be expected each year from the capital expended in planting and cultivating the beds.

In view of existing conditions, experiments were undertaken at Milford, Conn., during the summer of 1923 to perfect a method of artificial propagation by which oysters could be raised from the egg in sufficiently large numbers to make the process one of practical value, and to determine under controlled laboratory conditions the most important factors necessary and favorable for growth.

The author wishes to acknowledge his appreciation of the valuable and cordial cooperation rendered by the Connecticut Oyster Farms Co. in carrying on these investigations, and especially the help and suggestions given by Capt. Charles E. Wheeler of that company relative to various studies of the oyster situation and for generously supplying oysters, laboratory facilities, men, and boats for this work.

LIFE HISTORY OF THE OYSTER.

The common oyster (*Ostrea elongata* Solander) of the Atlantic and Gulf coasts of the United States is bisexual; that is to say, each individual possesses only one kind of reproductive organs, either male or female, which do not change during the life of the individual.

During the summer millions of eggs are discharged by the female oyster, which, after fertilization by the elements from the male, develop after a day or two into free-swimming larvae. These float and swim about with the tides and currents for a period of two or three weeks, depending upon the existing conditions, such as temperature, density, food, and tides. At the end of this free-swimming period they attach themselves, if possible, to such suitable objects as shells, rocks, brush, etc., which offer a clean hard surface to which they may adhere (see figs. 7, 8, and 9). Though ten to sixty million eggs are produced by a single full-grown oyster, only a few survive and grow to a size suitable for market. After the young oyster has attached itself, or "set," it is incapable of changing its position,

[2] "Oysters: The world's most valuable water crop." By Hugh M. Smith. National Geographic Magazine for March, 1923. Washington.

and if successful in surviving its natural enemies and occasional unfavorable conditions it will mature to marketable size in two to four years.

HISTORY OF ARTIFICIAL OYSTER CULTURE.

The idea of artificial oyster culture is not a new one. Since the first attempts in France in 1858 by Professor Coste to raise oysters by artificial means, very much has been done and written concerning the oyster and its culture. Unusual accounts of the immense production that might result from the artificial culture of the oyster have appeared from time to time in papers and books, of such plausibility that even practical oyster growers were led for a time to believe that with little labor great sums might be realized by raising oysters for the table. The first experiments in France were for the most part complete failures, but gradually, from a study of the localities where favorable results were obtained, a method such as may be found in use along the shores of France to-day was perfected. This method of artificial oyster culture comprised two very distinct branches—one being production, and the other rearing and fattening.

Production consists in placing adult oysters on the beds as a source of spawn and collecting the spat or embryo oysters that attach to suitable objects in the water after swimming about for a short time. These objects or collectors save vast numbers that otherwise would be lost and enable the oyster growers to harvest a crop each year on the grounds they have prepared.

Rearing consists in placing the spat, when sufficiently developed, in the best locations possible, where they will grow rapidly and be sheltered from the attacks of their natural enemies. When large enough for market the oyster is kept under such physical conditions as will fatten it and render it most suitable for the table. This method, as developed along the shores of France, is the most perfect and thorough system of oyster culture in the world. However, though methods similar in principle to those of the French have been carried on to some extent in the United States, they have been limited necessarily by the high cost of labor, different tidal and climatic conditions, and the difference in the species of oyster. In order to improve upon the methods of cultivation as practiced in the United States at present, attempts have been made since 1880 to develop a process whereby the oyster larvæ can be hatched and reared in receptacles or tanks until they set. These studies in artificial propagation were first carried on by Brooks, Ryder, Rice, and Winslow, but proved unsuccessful after several years of endeavor.

In carefully reviewing the results of their work the reason for failure is attributed mainly to one thing—filtration. The oyster eggs and larvæ are microscopic in size, and the greatest problem has been to find a means of permitting a flow of water and yet retaining the larvæ.

Later, in 1920, oyster larvæ were reared to setting size by W. F. Wells, of the New York State Conservation Commission, by the use of a milk separator for renewing the water in which the young oysters were kept. The process again proved successful in 1923, when a greater number of oysters was produced by artificial means,

but as yet this method has not been perfected to such an extent that it is commercially practicable. Further experiments with a new method of artificially propagating the oyster were conducted by the U. S. Bureau of Fisheries at Milford, Conn., during the summer of 1923, the results of which will be described in the following work.

OBJECT AND SCOPE OF THE INVESTIGATION.

The various reasons for undertaking experiments in artificial propagation are, first, to determine a reliable method for obtaining healthy, vigorous spawn in quantities; second, to devise a means for rearing the free-swimming oyster larvæ until they reach the setting stage; third, to make more extensive studies of the oyster larvæ under controlled conditions in regard to embryonic development, habits, food, and most favorable environmental conditions; fourth, to produce larvæ for tests in regard to the effect upon them of various chemicals in solution; fifth, to try out new materials for collecting and handling "set"; and sixth, to determine from the results obtained the possibilities of making artificial propagation successful on a practical commercial scale.

The many steps involved in artificially propagating oysters consist briefly of (1) obtaining natural spawn from the adults, (2) rearing the larvæ during the long free-swimming period, (3) placing suitable collectors in the water at the proper time for the attachment or "setting" of the larvæ, and (4) transferring the young attached oysters or "spat" to protected beds where conditions are most favorable for growth and development.

EQUIPMENT USED IN THE INVESTIGATION.

Careful observations of salt-water aquaria have indicated that, in general, metallic apparatus is unsuitable if a pure and natural water supply is to be maintained. The corroding action of the sea water upon brass, copper, galvanized iron, etc., renders them unfit as receptacles for the storage and conveyance of salt water. For this reason the equipment used in this investigation was constructed of wood, hard rubber, and glass when possible, in order that nearly natural conditions might be produced. The apparatus used consisted of one cylindrical 500-gallon wooden storage tank, one rectangular 100-gallon wooden spawning tank with trays, four rectangular 25-gallon rearing tanks, two small cylindrical rearing tanks, an air-compressor, rotary water pumps, glass pipe, and hard rubber and wood faucets. The problems of filtration were solved to a great extent by the use of a new material known as "filtros." It is a white, rigid, porous, artificial stone, composed essentially of silica, and is similar to a sand filter in block form. The various grades of uniform porosity in which it is made make it suitable for retaining materials or organisms of any definite size and still allow a good flow of water. The filtros blocks used in the experiments were 12 inches square and 1½ inches thick and were fitted into grooves in the rearing tanks as shown in Figure 1. Blocks of various densities were used in accordance with the growth and size of the larvæ, and after being in use for five or six days were easily cleaned with

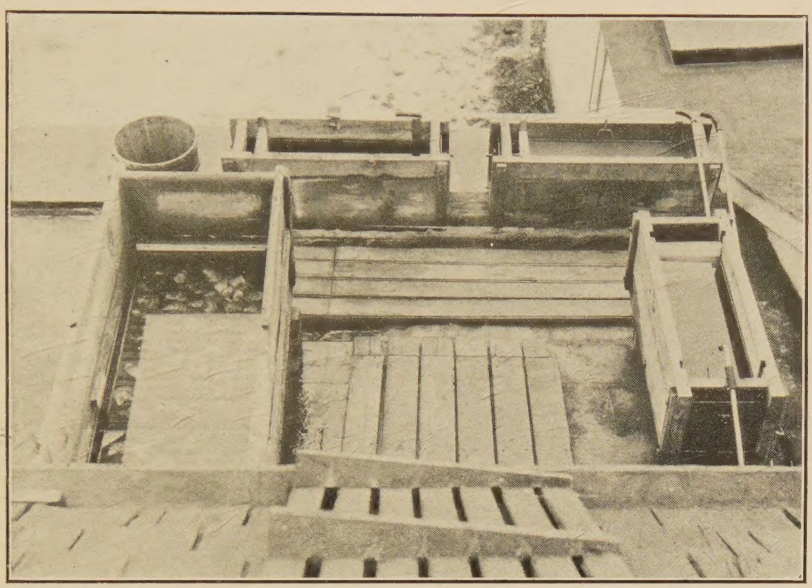

FIG. 1.—Experimental oyster hatchery, showing outdoor equipment consisting of one large spawning tank and three rearing tanks with filter blocks in place.

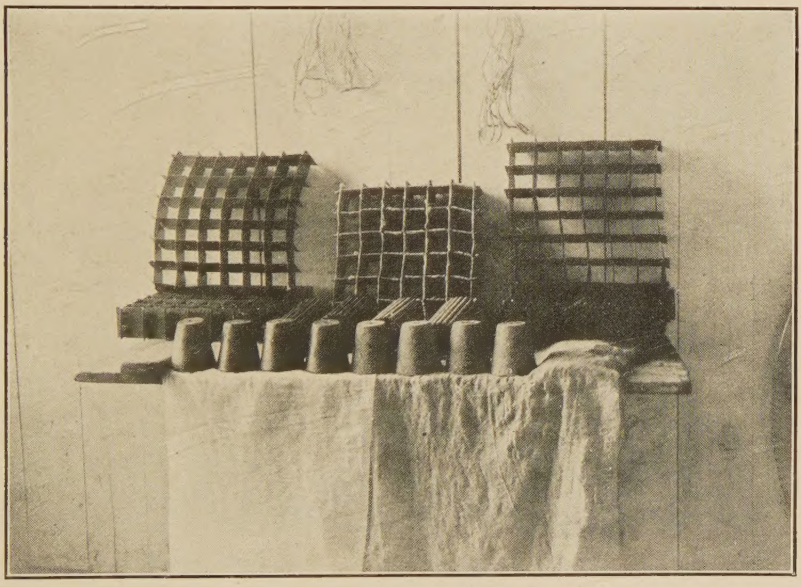

FIG. 2.—Artificial spat collectors coated with paraffin and sand, which allows heavy sets to break up into single oysters after one or two months.

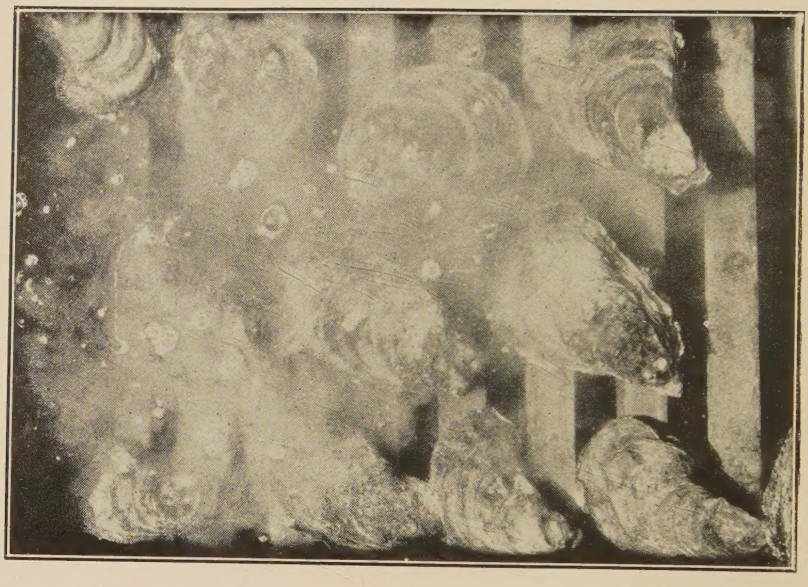

FIG. 3.—Adult oysters spawning naturally on tray in large spawning tank.

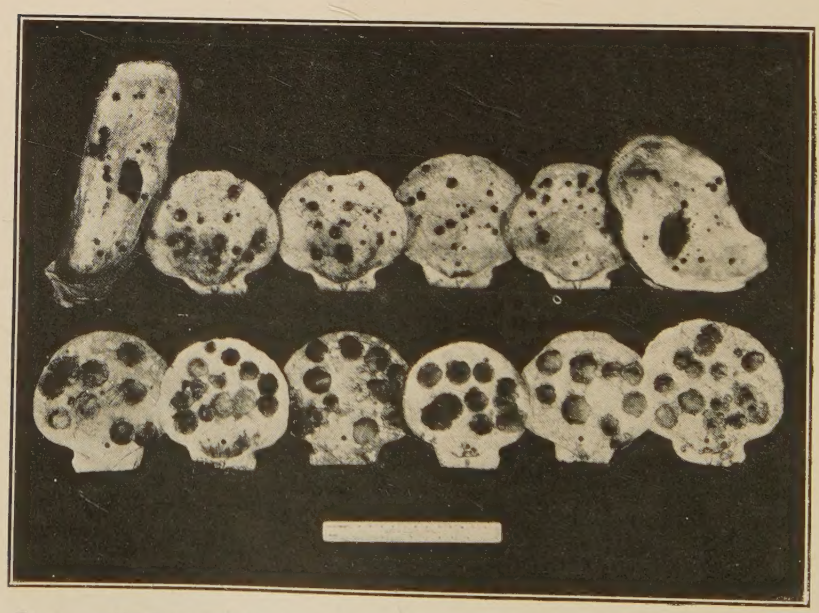

FIG. 4.—Artificially propagated oyster spat collected on sea-scallop shells for observation. Lower row, spat 7 weeks old; upper row, spat 3 weeks old. The three shells on the left in the upper row were kept in the rearing tank while the others were placed in the harbor.

a garden hose. For retaining the larvæ when 10 days old, fine monel metal screen was used and proved quite satisfactory for use in salt water.

SUCCESSFUL METHOD OF HATCHING AND REARING YOUNG OYSTERS.

In order that the various important factors affecting the artificial propagation of the oyster may be clearly understood, a résumé will first be made of the method that proved successful in hatching and rearing the young oysters. The brood stock of adult oysters used for producing spawn consisted of native oysters grown at Milford and southern oysters planted there by the bureau in 1919. These oysters were planted on shallow inshore beds in Gulf Pond, where the warm temperatures would mature them for spawning at an early date.

Numbers of the large oysters were placed on trays in the spawning tank, and the temperature was gradually increased until the water was filled with the spawn ejected by the adults (see fig. 3). Immediately after spawning had ceased, the oysters were removed and the eggs allowed to develop to the swimming stage in the warm water. Then the embryo oysters were transferred to the rearing tanks, and when supplied with running water they developed shells in 40 to 48 hours. The use of a mechanical agitator at this time helped greatly in bringing about a natural and rapid development of the oyster larvæ. For retaining the embryos a combination filter of loose, fine sand and filtros was used until the embryo oysters had reached the shell stage. From that time on the larvæ were held in by the filtros blocks of various grades, which were changed to suit the growth and size of the forms. When the larvæ were 10 days old, or older, they were held in by means of fine monel metal screens, which permitted an unusually good flow of water.

After a period of from 15 to 20 days the larvæ were ready to "set," and collectors of various materials were placed in the tanks for their attachment. In the first successful test over 150 spat were found "set" on the collectors, and in the last over 1,000 spat became attached (see fig. 4). The loss in numbers from the countless eggs produced by the adult oysters was traced to mechanical defects in making the filters fit closely and not to a mortality of the larvæ. After the spat had grown for a day or two in the rearing tanks they were transferred to favorable places in the harbor, where a maximum growth might be obtained. The care of the oyster after attachment is easily accomplished by the modern methods of culture.

REPRODUCTION AND DEVELOPMENT.

SELECTION OF THE OYSTERS.

The adult oysters used for the production of spawn were taken from the inshore beds early in the summer and from the deep-water offshore beds later in the season. In this way it was possible to obtain mature spawn from oysters in Long Island Sound from early in July until September, as the genital products of the oysters in the warm, shallow waters mature earlier than those of oysters in deep water.

The quantity of spawn found in the oysters is determined largely by the time of spawning and the previous weather conditions. Oysters one year old are capable of producing mature spawn, though for artificial propagation oysters three to five years old are considered the best. In sorting over the brood stock to be placed on the trays in the spawning tank only those oysters are selected that are free from the boring sponge, drill spawn, mussels, barnacles, hydroids, and tube-building worms, and which, from a noticeable amount of new growth around the edges of the shell, appear to be healthy. If necessary they can be scrubbed with a stiff brush to remove any excessive growths that may cover them.

SPAWNING.

The act of spawning consists in the discharge of the ripe reproductive elements into the surrounding water by both sexes of the oyster. The actively moving spermatazoa swarm about and fertilize the eggs, a single spermatazoon penetrating each egg membrane, the head of the spermatazoon passing on in after the tail has dropped off. The material of the head unites with that of the egg and causes the development of the egg cell into an embryo oyster.

The general method, since Brooks's initial experiment, for obtaining fertilized eggs has been to artificially mix the spermatazoa and eggs after stripping them from the ripened oysters, which have been opened. This method is unreliable, crude, wasteful, unnatural, and in most cases unnecessary, and undoubtedly accounts for many of the failures in the various attempts to artificially propagate oysters. It is impossible to determine how nearly ripe the spawn may be in any group of oysters without opening them, and consequently many are wasted before specimens apparently suitable for stripping are found. The experiments conducted at Milford have proved without a doubt that an enormous number of fertilized eggs can be produced by a natural process and the adults saved for future use. This process consists in placing the oysters in tanks of slowly running water, in the sunlight, where spawning is induced by the rising temperature. In every attempt made from July 10 to September 1 the oysters spawned readily and produced a greater amount of spawn than could be taken care of with the small-scale equipment. The spawning occurred at temperatures ranging from 68 to 75° F., and lasted over intervals of 15 to 30 minutes (see fig. 3). At higher temperatures than 75° the spawn was released slowly and immediately settled to the bottom of the tank, whereas normally it would be forcibly ejected into the water and would float about for some time. It was observed that the female oyster discharged the eggs in puffs at intervals of about 30 to 50 seconds, while the products from the male were emitted continuously in a slender, white, thread-like stream. In this way, when the trays of oysters were placed near the surface of the water, it was possible to proportion the numbers of each sex when spawning began, and one male was found to produce sufficient spermatazoa to fertilize the eggs from four females. The genital products can also be distinguished with the naked eye as the eggs appear as clouds of tiny white specks when discharged into the water, while the spermatazoa appear to fade away almost immediately after leaving the oyster. From these experiments it is evident that if oysters have reached sexual maturity, it is far better to have

them release the spawn naturally than to sacrifice the parent oysters by stripping it from them together with considerable débris and unripened eggs, which quickly foul the water. When spawning first begins the running water is shut off and in some cases the spawning is temporarily arrested by draining and flushing out the tank and refilling with a fresh supply, after which spawning takes place more vigorously than ever.

When the oysters have ceased spawning they are immediately removed from the tank and the eggs allowed to remain in the warm water until the first swimming stage is reached. The transfer of the swimming embryos to the rearing tanks may be accomplished in either one of two ways—first, by pouring them through No. 20 bolting silk to remove any possible débris or enemies which may have gotten into the water; or second, by having a steady stream of water from the surface of the spawning tank to the rearing tanks, which will carry over only the most vigorous of the swimming embryos and leave any unfertilized eggs, débris, etc., behind.

In one instance (on July 26) a group of 11 month-old oysters spawned for over five minutes at a temperature of 69½°. A sample of this observed in a watch glass developed as normally as that of the older oysters.

EMBRYONIC DEVELOPMENT.

The young oyster that develops from the egg is extremely unlike the adult and undergoes a variety of changes until some time after it sets, when it acquires the asymmetrical characteristics of the adult. The fertilized egg develops into a swimming form in from 6 to 10 hours at moderate temperatures, and when about two days old acquires two tiny shells that continue to grow and surround the body of the larva. This early stage is characterized by a straight hinge where the shells are joined together, and precedes the most critical period in the development of the larva. At the time that the straight hinge disappears and the larva becomes more rounded in shape, it has apparently used up the yolk supply from the egg and is beginning to take in microscopic food from the water. If it survives this period, it can be reared through the succeeding stages without difficulty.

As the larva increases in size one valve becomes much deeper than the other and has a more prominent umbone, which enables one to distinguish the oyster larva from that of any other bivalve.[3] The deeper valve is the left one and that by which the oyster later becomes attached. After swimming about for a period of two or three weeks the larva becomes about one-third of a millimeter (one seventy-fifth of an inch) long, and if the proper conditions are present it "sets."

SETTING.

The terms "fixation," "spatting," and "setting" are applied to the attachment of the larva to some firm, clean surface with which it comes in contact. The left valve becomes attached by means of a shelly secretion of the left lobe of the mantle, which serves to cement it to the surface the larva has selected. In artificial propagation the

[3] The oyster and the oyster industry of the Atlantic and Gulf coasts. By E. P. Churchill, jr. Appendix VIII, Report U. S. Commissioner of Fisheries, 1919 (1921). Washington.

various collectors are placed in the tanks previous to the setting stage and become quite evenly covered with the spat. The number of spat desired on any particular collector can be regulated by the length of time they are left in the tanks and by observing the numbers that have become attached from time to time.

GROWTH OF SPAT.

The growth of the oyster spat after "setting" is quite rapid under favorable conditions. Observations made in 1922 of the growth from the time of setting showed that in 13 days the spat attained an average size of one-fourth of an inch (6 mm.) when placed just below the surface of the water. The daily average sizes (maximum diameters) of set measured in August, 1922, are given below in millimeters:

Just attached (larval shell only)	0.33
1-day-old spat	.402
2-day-old spat	.603
3-day-old spat	.737
4-day-old spat	1.005
5-day-old spat	1.139
6-day-old spat	1.273
7-day-old spat	1.675
8-day-old spat	2.144
9-day-old spat	2.680
10-day-old spat	3.216
13-day-old spat	6.000
18-day-old spat	10.000
23-day-old spat	14.000

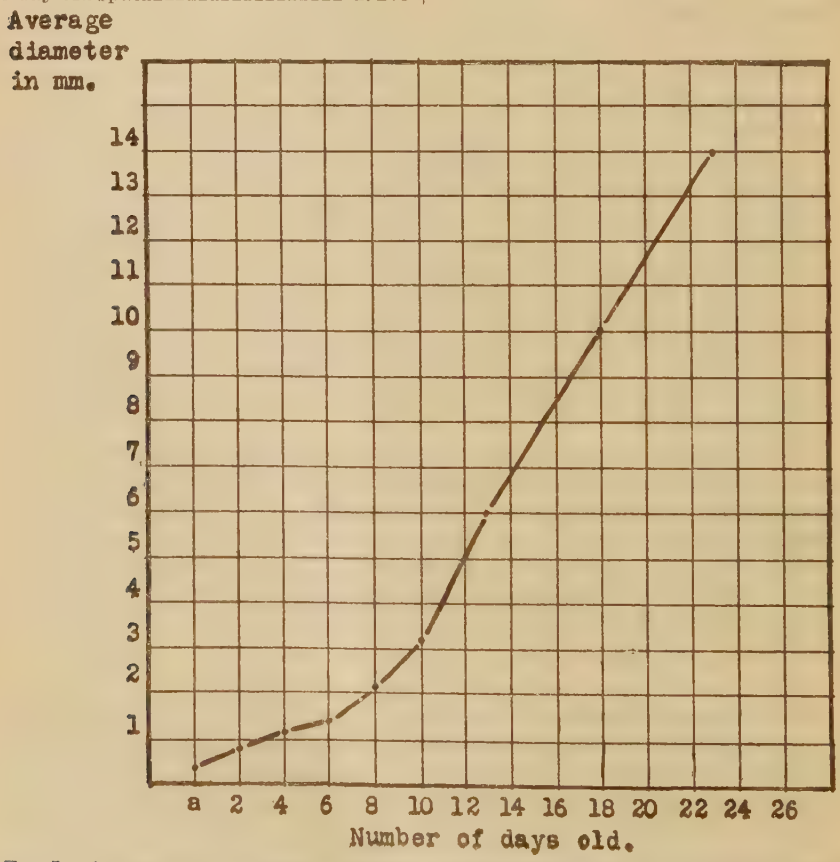

FIG. 5.—Average rate of growth of spat after setting, from August 2 to August 25, 1922, Milford Harbor, Conn. *a*, Size of spat at time of setting.

Artificially grown spat that set on sea-scallop shells placed in the rearing tanks on August 2, 1923, attained an average growth of 27 mm. ($1\frac{1}{16}$ inches) in two months. Some of the others, which set on August 18, 1923, were kept in the rearing tanks, while the rest were placed in the harbor. The average growth, for a period of three weeks, was 12.5 mm. for those in the harbor and 14 mm. for those kept in the tanks (see fig. 4). The temperature of the running water in the tanks was generally higher than that found in the harbor and undoubtedly accounts for the better growth. In one year the oysters attain an average length of 3 inches and width of $1\frac{3}{4}$ inches when placed on inshore beds in Milford Harbor. In two years they can be taken up for the half-shell trade, and measure on the average $4\frac{1}{4}$ inches in length and $2\frac{3}{4}$ inches in width, and are much deeper. This rapid development occurs only on the inshore flats where food is abundant and the temperature of the water is high. On the deep-water beds of the Sound it requires about four years for an oyster to attain a length of 4 or 5 inches, or a marketable size.

FACTORS OF ENVIRONMENT.

TEMPERATURE.

The temperature of the water during the development of the oyster from the egg to the spat is of considerable importance. It is undoubtedly the greatest influence in determining the rate at which growth and development take place and is coincident with the success of the experiments. The life processes of the egg, embryo, and larval oyster are hastened by a high temperature and retarded by a low one. A violent change or extreme high or low temperature will kill the young oysters or considerably impair their vitality. Several attempts were made to hasten the development of larvæ by keeping the temperature from 80 to 85° F., but this invariably resulted in a total loss of the forms. In the successful experiments the temperature ranged from 65 to 75°, and was kept as near 70° as possible.

DENSITY OF WATER.

The water used for rearing the larvæ was pumped on the flood tide and had a density ranging from 1.019 to 1.0218 during July and August. Just how great an influence the density of the water has on the oyster embryos can not be stated, though it seems probable that any considerable change in this respect would be detrimental to such a delicate organism. Changes in density and temperature are closely correlated so that it is hardly possible to state the exact influence of either without allowing for the other. Due to the supply of fresh water from the land the density of the water in the harbors and on the inshore beds is generally lower than that found offshore, and when within a range of density between 1.011 and 1.022 is most suitable for oyster growth.

LIGHT.

A comparative study of conditions in the rearing tanks that were placed in the sunlight with those that were kept in indirect light

strongly indicates that for the purpose of artificial propagation the latter are more desirable. The tanks receiving less light maintained a more even temperature, kept clean longer, and developed the larvæ more rapidly than those placed in the sunlight. Sunlight and high temperatures do not accelerate the development of the larvæ but promote the growth of bacteria, infusoria, and minute plants which foul the water and necessitate frequent changes of tanks and filters. The setting of the larvæ occurred as heavily on the light side of the collecting shells as it did on the darkened side as both sides were equally clean.

WATER SUPPLY.

A pure and uncontaminated supply of salt water is essential and necessary for the propagation of any marine animal. By pumping on the flood tide the water in Milford Harbor was found suitable but not ideal for experimental work. Each year a small scattered set occurs in the harbor, which indicates that in general conditions there are favorable for the development of oyster larvæ. The water was pumped to the 500-gallon reservoir at every flood tide when possible, in order to maintain a good quality in storage for distribution to the spawning and rearing tanks. The reservoir was drained and cleaned occasionally though very little sediment was found to have settled in the bottom.

From the reservoir five glass pipe lines with separate wood valves conveyed the salt water to the various tanks where it was projected through fine sprays in order to create a circulation. The water level in the rearing tanks was controlled by hard-rubber overflow valves that were located at one end of the tanks outside of the filters.

FOOD AND ENEMIES.

The food of the oyster larvæ consists of ultra-minute organisms or nannoplankton, which are found in abundance in ordinary sea water. The plankton was excluded from the water supply by means of a net made of No. 20 bolting silk through which the water was pumped before going into the reservoir. This also removed all large known enemies of the larvæ and allowed only the nannoplankton to pass through.

The presence of infusoria in abundance in the tanks is an indication that conditions are becoming unsatisfactory and foul as a result of the death and decomposition of many of the embryos. To separate the healthy embryos from these organisms, which collected at the bottom of the tanks, was at first a problem but by allowing a good overflow of water to a new tank the more vigorous ones soon swam out to the new quarters. As the larvæ increase in size and pass the straight-hinge stage they can be readily separated from infusoria, sediment, etc., by the use of bolting silk. However, a troublesome growth of infusorians was experienced only in the tanks placed in sunlight and with spawn taken from artificially fertilized eggs, when making various tests with it in comparison with natural spawn under the same conditons.

ÆRATION.

Æration as a means for producing conditions favorable to the development of the eggs and larvæ was tested out in many experiments. Apparatus of many designs with varying degrees of æration proved useless when tried out with the young oysters at every stage of development. It was hoped to carry the minute embryo oysters through the first stages in water that was purified and agitated by compressed air, as the filtros blocks were not fine enough to restrain them until they had developed shells, but their development in ærated water was slow and generally resulted in an early death of the embryos or produced shell forms of such decreased vitality that they lived only a short time. Winslow's experiments in 1822 to oxygenate the water by æration likewise proved unsuccessful, and this factor as a necessary step to success is questionable.

RUNNING WATER.

The most important result of the summer's investigation into the controlling factors necessary for success in artificial propagation is that oyster eggs and larvæ will develop and grow in salt water aquaria as fast and as vigorously as they will in nature if supplied with *running water*. The first batch of spawn placed in the unseasoned apparatus was given a constant supply of water from the beginning in spite of the fact that many got around the filters and were lost. They developed normally from day to day and "set" with practically no mortality 15 days after spawning. In the succeeding experiments the water supply was diminished and every attempt made to retain all of the larvæ, with the result that stagnation and fouling occurred and all of the forms died. The next successful experiment was accomplished by providing a good supply of running water and would have yielded a greater crop of spat had it been possible to prevent the soft embryonic forms from passing through the filters.

By introducing the water into the rearing tanks in fine jets it was easy to produce a circulation and agitation throughout the tanks similar to that found in nature. For carrying the embryos through to the shell stage, a glass rod agitator proved effective for use with a very slight flow of water. This prevented a heavy loss of the forms up the shell stage but was not perfected in operation until September, when it became too cold to conduct the experiment further.

FILTRATION.

Oyster eggs and embryos are so extremely small that they will pass through felt or the finest bolting silk and consequently it can readily be seen that it is a difficult problem to create a flow of water and at the same time prevent the passage of such minute organisms. A method for accomplishing this was not found until the first week in September, when thousands of healthy straight-hinge larvæ were produced but could not be reared to setting size because of the cold weather when water temperatures dropped overnight to 50 and 54° F. and soon killed them.

The apparatus that solved this perplexing problem consisted of a half barrel equipped as shown in Figure 6. The filtros plate was

covered with a 2-inch layer of fine white sand and the rate of flow through it was regulated by the valve *e*. The half barrel was filled with water up to about 6 inches over the sand and freshly fertilized eggs placed in it. A fine stream of water from the faucet *a* kept up a constant circulation in the barrel from the time the eggs were put in. Tests from time to time at the drain *e* indicated that none of the eggs were passing out through the sand or filtros, but as no trace could be found of the embryos in the barrel above the sand layer it

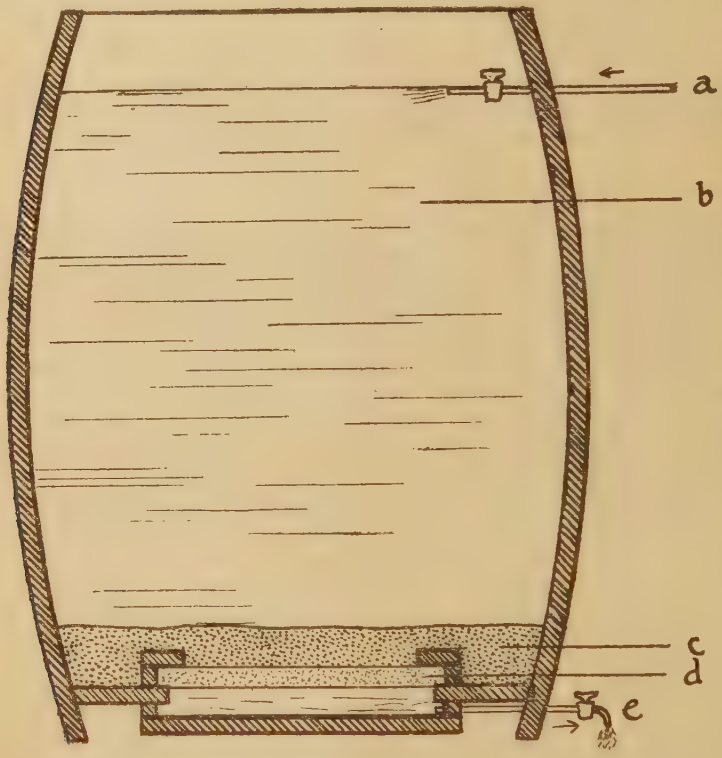

FIG. 6.—Barrel equipped for developing oyster embryos to the shell stage. *a*, Fine stream for supplying salt water and circulation in the barrel; *b*, salt water containing embryos; *c*, 2-inch layer of fine sand; *d*, filtros block; *e*, drain pipe with control valve.

was thought at first that they had died and that the apparatus was a failure. However, after a period of 48 hours, it was decided to wash out the sand and try a new batch of spawn. In turning a heavy stream of water into the barrel and opening wide the valve *e* it was found that thousands of vigorous larvæ with well-developed shells were washed out into the triple layers of bolting silk placed there. This was indeed encouraging, as the filtros blocks were suitable for rearing them once they had developed shells. This experiment was repeated several times with success and it is to be regretted that the lateness of the season prevented carrying the larvæ through to setting and making the summer's work one of production as well as theory.

FIG. 7.—One-year-old oysters that set on tar-coated pound nets in Great South Bay, Long Island, 1921. Such a collector is suitable for producing excellent single oysters from heavy sets, with little mortality from overcrowding.

FIG. 8.—Pound stakes covered with a heavy set of year-old oysters from Great South Bay, 1921. The convex surface of brush, stakes, tarred rope, etc., will produce good oysters when thickly covered with spat.

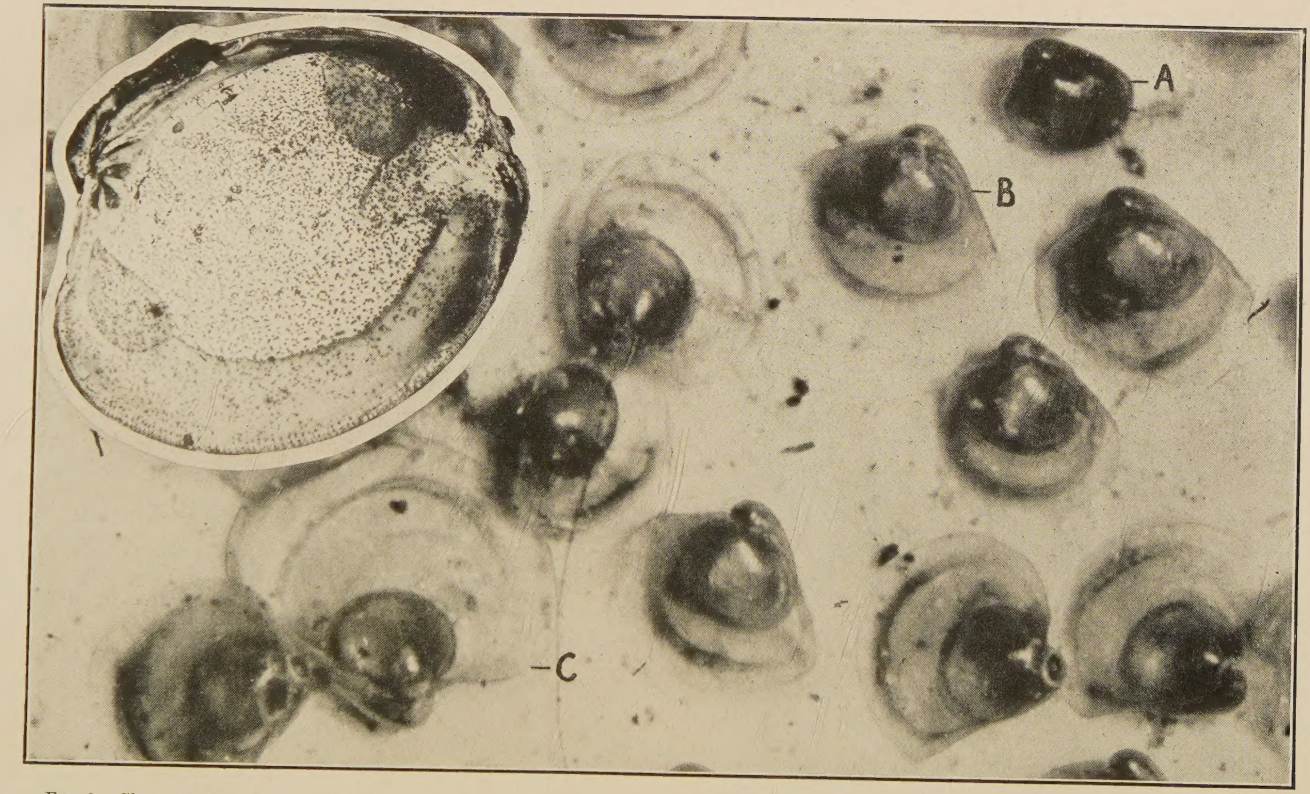

FIG. 9.—Clamshell heavily set with thousands of young spat, actual size (inset), and a portion of the shell enlarged to show the detailed structure of the spat. *A*, Spat just attached; *B*, spat one day old; *C*, spat two days old. The clamshell was taken from Great South Bay in 1921 and illustrates the heavy loss of young oysters that must occur on such a hard, firm material on which all but 8 or 10 are lost from overcrowding and suffocation.

COLLECTION AND TRANSPLANTING.

An important consideration in placing artificial propagation on a commercial scale is that of collecting and transplanting heavy "sets" by a method that would be practical and efficient. A variety of collecting materials was tried out in Milford Harbor to determine just how certain ones would weather unfavorable conditions on the beds. A new type of collector for handling artificially propagated oyster spat was made from cardboard egg-crate partitions, which were dipped in hot paraffin and then covered with coarse sand (see fig. 2). They quickly sank to the bottom and were heavy enough to withstand tides and storms in a moderate depth of water. The partitions remained in place for over a month when suspended at the surface of the water, and longer when placed on the bottom, and regardless of how they are dropped into the water they settle in such a way that there is no chance of smothering the spat. They are cheap collectors, capable of collecting thousands of spat and in two or three months will break up, producing large numbers of small single oysters, the most desired product in oyster culture to-day. The degree of spat concentration that is most suitable will be determined by future experiments.

Other objects, such as brush, rope, netting (fig. 7), shells (fig. 9), tin cans, etc., coated with paraffin and sand, asphalt, cement, and plaster of Paris were also found suitable to some extent as collectors. The artificially propagated spat were caught on a sea-scallop, clam and oyster shells, and small clay flower pots, as there were not sufficient numbers to warrant using the larger collectors. The loss of spat from handling or other agencies was less than 1 per cent, and in transplanting them to the most suitable grounds no greater loss should be sustained if they are properly handled. The problem of catching and handling the set is insignificant in comparison with that of producing larvæ ready to attach themselves, and improvements in this respect will quickly come when a dependable method for the latter has been perfected.

SUMMARY.

The primary object in writing this paper is to lay before practical oyster growers and biologists the various problems that have made artificial propagation of the oyster a difficult task, and to briefly describe experiments used in finding some solution for them. The summer's work was conducted for the purpose of studying these problems more thoroughly and to make detailed observations of the many natural conditions in the environment of the oyster to determine the influence they exert upon the eggs, embryos, and free-swimming larvæ. The continuation of this work in the future will aim to develop this method on a production basis so that it may be perfected to such an extent as to be of value to the practical oyster industry.

Northern oyster growers are to-day paying as high as $1,000 for 1,000,000 year-old oysters, or for one-fiftieth of the number that a single full-grown female oyster is capable of producing.

Surely a system of artificial propagation that can produce the same results with a smaller expenditure can be perfected in the future if natural conditions are studied, imitated, and placed under control. Such an important object can hardly be attained at a single leap, but eventually it will be reached after a series of careful and painstaking experiments and the accumulation and study of facts have broadened our knowledge in regard to the habits and requirements of the oyster throughout its life history.

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